

USAWC STRATEGY RESEARCH PROJECT

UNMANNED AERIAL VEHICLES: REPLACING THE ARMY'S COMANCHE HELICOPTER?

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ABSTRACT

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This strategic research project explores the possibility of unmanned aerial vehicles replacing the Comanche Helicopter in its doctrinal missions. This research consolidates the aviation critical tasks required to support reconnaissance, security, and movement-to-contact missions, evaluates the capabilities of unmanned aerial vehicles, and analyzes unmanned aerial vehicles capabilities against those aviation critical tasks. This research will also consider likely future unmanned aerial vehicle capabilities as well. Though key UAV capabilities are equal to or better than similar systems in the Army's current helicopters, this analysis reveals that unmanned aerial vehicles can only perform 67% of the reconnaissance critical tasks, 50% of the security critical tasks, and 25% of the movement-to-contact critical tasks required to achieve mission success. These percentages demonstrate that unmanned aerial vehicles cannot fulfill the role of the Comanche Helicopter.

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UNMANNED AERIAL VEHICLES: REPLACING THE ARMY'S COMANCHE HELICOPTER?

The United States Army has some critical funding decisions concerning the future of its aerial reconnaissance and security forces. While some senior military leaders are pushing for the funding of the Comanche Helicopter program,¹ others want to kill the Comanche Helicopter program and use the money, in part, to fund unmanned surveillance and combat aircraft.² Though unmanned aerial vehicles (UAV) are executing increasingly more complex roles in military operations, can unmanned aerial vehicles now, or in the next ten years, fulfill the role of the Comanche Helicopter?

To answer this question, a five step process will be used to compare unmanned aerial vehicle capabilities against helicopter mission requirements. First, compile a list of Army Aviation doctrinal missions performed by the Army's current reconnaissance helicopter, the OH-58D Kiowa Warrior, as a model for the mission roles of the future reconnaissance helicopter, the RAH-66 Comanche. Second, identify the critical tasks supporting those doctrinal missions. Third, investigate the current and near-term future (**see Appendix 1, Glossary of Terms**) capabilities and limitations of a representative sample of unmanned aerial vehicles. Fourth, compare the capabilities and limitations of unmanned aerial vehicles against the aviation critical tasks using decision criteria. Fifth, if, after completing step four, there is a shortfall between unmanned aerial vehicle capabilities and aviation mission requirements, briefly discuss options to improve unmanned aerial vehicle effectiveness.

DETERMINE DOCTRINAL MISSIONS – STEP 1

Army Aviation's capstone manual is FM 1-100, Army Aviation Operations.³ FM 1-100 divides Army aviation missions into three broad categories: Combat; Combat Support; and Combat Service Support.⁴ The OH-58D Kiowa Warrior performs combat aviation missions; therefore, this research will focus on those missions. FM 1-100 identifies seven Combat Aviation Missions. They are listed and briefly discussed below:

- **Reconnaissance operations** obtain information by visual observation or other detection methods.⁵
- **Security operations** provide maneuver space, reaction time, and protection to a force.⁶
- **Attack helicopter operations** are conducted to destroy enemy forces.⁷

- **Air Assault operations** enable air assault forces (combat, combat service, and combat service support) to maneuver on the battlefield.⁸
- **Theater Missile Defense operations** are conducted to integrate and enhance the joint force's capabilities to destroy incoming missiles in-flight, reduce the vulnerability of friendly forces from the effects of theater missile attacks, and destroy hostile missile capability.⁹ Army aviation executes deep operations to attack hostile elements of the theater missile systems.¹⁰
- **Special operations** are dedicated to support special operations across the full range of military operations.¹¹
- **Support by fire** is a mission given to attack helicopters, directing them to establish a base of fire or an overwatch position.¹²

Though the OH-58D can participate in all seven combat missions, this research will focus on reconnaissance and security missions. FM 1-100, as the capstone aviation manual, was a fundamental source, but the most thorough analysis of critical tasks is in FM 1-114, Air Cavalry Squadron and Troop Operations.

DETERMINE CRITICAL TASKS SUPPORTING DOCTRINAL MISSIONS – STEP 2

FM 1-114, Air Cavalry Squadron and Troop Operations, provides a detailed evaluation of aviation reconnaissance and security missions. FM 1-114 states that reconnaissance operations are conducted to obtain information about the activities and resources of an enemy or about the meteorological, hydrographic, or geographic characteristics of a particular area.¹³ This definition is consistent with FM 1-100. FM 1-114 further notes three types of reconnaissance: Route; Zone; and Area.¹⁴ Each of these reconnaissance operations requires a more detailed discussion to highlight the critical tasks.

A route reconnaissance is conducted to obtain information about a specific route and all adjacent terrain from which the enemy could influence movement along the route.¹⁵ Below are the seven critical tasks for route reconnaissance operations listed in FM 1-114:¹⁶

- Reconnoiter all terrain the enemy can use to dominate movement along the route.
- Reconnoiter all terrain within the zone.
- Locate sites for constructing hasty obstacles to impede enemy movement.
- Reconnoiter all defiles along routes for possible ambush sites and locate a bypass.

- Locate a bypass around built-up areas, obstacles, and contaminated areas.
- Find and report all enemy that can influence movement along the route.
- Report route information.

A zone reconnaissance is conducted to obtain information concerning all routes, obstacles (including chemical and radiological contamination), terrain, and enemy forces within a zone defined by boundaries.¹⁷ Below are the ten critical tasks for zone reconnaissance operations listed in FM 1-114:¹⁸

- Find and report all enemy in zone.
- Reconnoiter all specific terrain within the zone.
- Report reconnaissance information.
- Reconnoiter all terrain within the zone.
- Find suitable covered and concealed air avenues of approach.
- Determine significant adverse weather.
- Locate a bypass around built-up areas, obstacles, and contaminated areas.
- Inspect and classify all bridges, overpasses, underpasses, and culverts within the zone.
- Locate fords and crossing sites near all bridges in zone.
- Locate all mines, obstacles, and barriers in the zone within its capability.

An area reconnaissance is conducted to gather intelligence or to conduct surveillance of a specific area.¹⁹ Below are the nine critical tasks for area reconnaissance operations listed in FM 1-114:²⁰

- Reconnoiter specific terrain within the area and dominant terrain outside the specific area from which the enemy can influence friendly operations.
- Report reconnaissance information.
- Find and report all enemy within the area.
- Reconnoiter all terrain within the area.
- Determine significant adverse weather.
- Locate a bypass around built-up areas, obstacles, and contaminated areas.

- Inspect and classify all bridges, overpasses, underpasses, and culverts within the area.
- Locate fords and crossing sites near all bridges in the area.
- Locate all mines, obstacles, and barriers in the zone within its capability.

Table 1 below is a consolidated list of all the critical tasks required to perform area, zone and route reconnaissance missions from FM 1-114:

CONSOLIDATED RECONNAISSANCE CRITICAL TASKS FROM FM 1-114	
1. Report Reconnaissance information.	
2. Find and report all enemy in zone.	
3. Reconnoiter all terrain within the area, with the zone, along the route, and all terrain that can dominate the area.	
4. Determine significant adverse weather.	
5. Inspect and classify all bridges, overpasses, underpasses, and culverts within the area.	
6. Locate a bypass around built-up areas, obstacles, and contaminated areas.	
7. Locate fords and crossing sites near all bridges in zone or area.	
8. Locate all mines, obstacles, and barriers in the zone within its capabilities.	
9. Locate sites for constructing hasty obstacles to impede enemy movement.	
10. Reconnoiter all defiles along route for possible ambush sites and locate a bypass.	
11. Find suitable covered and concealed air avenues of approach.	

TABLE 1

The other combat aviation mission this research project will focus on is security operations. FM 1-114 states that security operations provide maneuver space, reaction time, and protection to a friendly force.²¹ There are five security missions in FM 1-114: Screen; Guard; Cover; Area Security, and Air Assault Security.²²

A screen protects by providing early warning to the friendly force through the communication of real-time combat information.²³ This real-time information provides the supported friendly force time to orient to meet the threat.²⁴ The screen is the least protective security mission,²⁵ but Army helicopters can perform the screen without assistance.²⁶ Helicopters have four critical tasks when performing screen operations:²⁷

- Maintain continuous surveillance of all battalion-sized avenues of approach.
- Destroy or repel all enemy reconnaissance forces.
- Locate the lead elements of the enemy order of battle (enemy force immediately following enemy reconnaissance forces).

- Maintain contact with the enemy order of battle, report their activities, and harass the enemy while displacing.

The second security mission, guard operations, protects a friendly force from enemy ground observation, direct fire, and surprise attack.²⁸ The guard mission is not normally assigned to helicopters alone, but they can execute the mission in concert with ground forces.²⁹ When performing a guard mission in concert with ground forces, the helicopters execute the following six critical tasks:³⁰

- Perform reconnaissance along the main body's axis of advance.
- Maintain continuous surveillance of enemy battalion-sized avenues of approach.
- Maintain contact with the lead combat element of the friendly force.
- Reconnoiter the zone between the main body and the guard force battle positions.
- Destroy or repel enemy reconnaissance and security forces.
- Defeat, repel, or fix enemy ground forces before they engage the main body with direct fire.

The third security mission, covering force operations, is conducted by a tactically self-contained, independent force that can deceive, disorganize, and destroy enemy forces.³¹ It is normally a combined arms force, containing, among other assets, helicopters. Helicopters supporting this mission use reconnaissance and security critical tasks listed earlier.³² However, there is one exception, the movement-to-contact operation, which will be addressed later.

The fourth and fifth security missions, Area Security and Air Assault Security operations,³³ are executed using the same critical tasks already discussed in screen and guard operations. Therefore, Area Security and Air Assault Security operations do not add any critical tasks to the list of tasks that will be used later to compare helicopters to unmanned aerial vehicles.

Table 2 below is a consolidated list of all the critical tasks required to perform security missions in accordance with FM 1-114:

CONSOLIDATED SECURITY CRITICAL TASKS FROM FM 1-114
1. Maintain continuous surveillance of all battalion-sized avenues of approach.
2. Destroy or repel all enemy reconnaissance and security forces.
3. Perform reconnaissance along the main body's axis of advance.
4. Locate the lead elements of the enemy order of battle.
5. Maintain contact with the enemy order of battle, report their activities, and harass the enemy while displacing.
6. Maintain contact with the lead combat element of the friendly force.
7. Reconnoiter the zone between the main body and the guard force battle positions.
8. Defeat, repel, or fix enemy ground forces before they engage the main body with direct fire.

TABLE 2

A movement-to-contact operation, a separate mission discussed earlier, is similar to a zone reconnaissance, except its focus is on finding the enemy. Table 3 below is a consolidated list of all the critical tasks performed during movement-to-contact missions in accordance with FM 1-114:³⁴

<u>MOVEMENT-TO-CONTACT CRITICAL TASKS FROM FM 1-114</u>
1. Reconnoiter forward or to the flanks of ground forces.
2. Harass and impede enemy elements.
3. Direct ground elements to the vicinity of enemy units and support friendly ground forces with direct fires.
4. Maintain surveillance of enemy forces

TABLE 3

This completes the identification of the reconnaissance, security, and movement-to-contact missions and their associated critical tasks from FM 1-114. Though other Army doctrinal manuals discuss aviation reconnaissance and security missions, FM 1-114's discussion is the most complete and detailed. Table 4 below is a consolidated list of critical tasks performed by Army helicopters during all reconnaissance, security, and movement-to-contact missions in accordance with FM 1-114:

CONSOLIDATED RECONNAISSANCE, SECURITY AND MOVEMENT TO CONTACT CRITICAL TASKS FROM FM 1-114
1. Report Reconnaissance information.
2. Find and report all enemy in zone
3. Reconnoiter all terrain within the area, with the zone, along the route, and all terrain that can dominate the area.
4. Determine significant adverse weather
5. Inspect and classify all bridges, overpasses, underpasses, and culverts within the area
6. Locate a bypass around built-up areas, obstacles, and contaminated areas
7. Locate fords and crossing sites near all bridges in zone or area.
8. Locate all mines, obstacles, and barriers in the zone within its capabilities
9. Locate sites for constructing hasty obstacles to impede enemy movement
10. Reconnoiter all defiles along route for possible ambush sites and locate a bypass
11. Find suitable covered and concealed air avenues of approach
12. Maintain continuous surveillance of all battalion-sized avenues of approach
13. Destroy or repel all enemy reconnaissance and security forces
14. Perform reconnaissance along the main body's axis of advance
15. Locate the lead elements of the enemy order of battle
16. Maintain contact with the enemy order of battle, report their activities, and harass the enemy while displacing.
17. Maintain contact with the lead combat element of the friendly force
18. Reconnoiter the zone between the main body and the guard force battle positions
19. Defeat, repel, or fix enemy ground forces before they engage the main body with direct fire.
20. Reconnoiter forward or to the flanks of ground forces
21. Harass and impede enemy elements.
22. Direct ground elements to the vicinity of enemy units and support friendly ground forces with direct fires
23. Maintain surveillance of enemy forces.

TABLE 4

Having completed the first two steps of this research, identifying the doctrinal missions performed by Army helicopters and compiling a list of critical tasks they execute in several important missions, the next step is to evaluate the current and near-term future (see **Appendix 1, Glossary of Terms**) capabilities and limitations of UAVs.

INVESTIGATE CURRENT AND NEAR-TERM FUTURE UAV CAPABILITIES AND LIMITATIONS – STEP 3

Unmanned aerial vehicle (UAV) systems are currently divided into two broad categories, Tactical and Endurance.³⁵ Tactical unmanned aerial vehicles are defined as those systems with

a range of up to 200 kilometers.³⁶ Endurance unmanned aerial vehicles are generally those systems whose range exceeds 200 kilometers.³⁷ Whenever possible, this research will focus on tactical unmanned aerial vehicle systems since they most closely replicate the mission requirements of the OH-58D Helicopter. The United States Army, Navy, Air Force, and Marine Corps each have unmanned aerial vehicle programs and all four services are developing new systems for their unique requirements. A representative sample of seven systems that are either fielded or in development will demonstrate the capabilities of UAVs.

Two of these seven unmanned aerial vehicles are United States Marine Corps systems, Dragon Warrior and Dragon Eye. The Dragon Warrior has a unique removable wing design that allows this unmanned aerial vehicle (UAV) to function as either a rotary or fixed wing vehicle.³⁸ Due to this feature, Dragon Warrior is a versatile system capable of operating in confined urban environments or conducting operations over a range of 100 nautical miles.³⁹ The Dragon Warrior is capable of operating aloft for 2.5 hours,⁴⁰ can reach speeds up to 135 knots per hour,⁴¹ and supports multiple sensor payloads, including electro-optical and infrared subsystems.⁴² The Dragon Warrior's navigation is controlled by preprogramming waypoints **(see Appendix 1, Glossary of Terms)** or by autonomous navigation **(see Appendix 1, Glossary of Terms)**.⁴³

The other Marines Corps system, Dragon Eye, is a five pound, back-packable UAV designed to provide the small unit commander the capability to see over the next hill or around the next building.⁴⁴ Dragon Eye has a range of ten kilometers, a maximum speed of 35 knots, and can stay aloft for one hour.⁴⁵ Its payload sensors include full motion color, low light, and infrared cameras.⁴⁶ Dragon Eye navigates via pre-assigned GPS waypoints, which can be reprogrammed during flight, or by autonomous navigation.⁴⁷

The one representative sample UAV pioneered by the United States Navy is a large, helicopter-like unmanned aerial vehicle, called Fire Scout. The Fire Scout is a vertical take-off and landing UAV, which provides situational awareness and precision targeting for the US Navy and Marine Corps.⁴⁸ Fire Scout has a range of 110 nautical miles, a maximum speed of 125 knots, and can stay airborne for six hours.⁴⁹ Its payload includes electro-optical and infrared sensors, a laser rangefinder/designator, synthetic aperture radar **(see Appendix 1, Glossary of Terms)**, a movement target indicator capability **(see Appendix 1, Glossary of Terms)**, and signals intelligence sensors.⁵⁰ The Fire Scout navigates in the autonomous mode.⁵¹

The United States Air Force's (USAF) focus on aerospace power led it to develop endurance UAVs. As mentioned earlier, an endurance unmanned aerial vehicle has a range

exceeding 200 nautical miles. Although this research is focused on tactical UAVs, examining USAF systems is worthwhile because of their impressive capabilities. The two Air Force UAVs in the representative sample are the Predator and Global Hawk.

Predator provides long-range, long-dwell, near-real-time imagery intelligence to satisfy reconnaissance, surveillance, and target acquisition mission requirements.⁵² The Predator has a range of 500 nautical miles, a maximum speed of 130 knots, and can remain airborne for over 20 hours.⁵³ Its payload includes electro-optical sensors, infrared sensors, and synthetic aperture radars.⁵⁴ The Predator is remotely piloted by a ground station with three additional technicians monitoring the flow of sensor information.⁵⁵ The Predator has a maximum operating altitude of 25,000 feet.⁵⁶ Predator's initial operational deployment was in Bosnia in 1995.⁵⁷ More recently, Predator was armed with hellfire missiles. To date, Predator UAVs have successfully launched over fifty hellfire missiles in combat operations.⁵⁸

The other USAF system, Global Hawk, provides high altitude, long-dwell time, and wide area surveillance to meet operational and strategic reconnaissance needs.⁵⁹ Global Hawk has a 3,000 nautical mile range,⁶⁰ a maximum speed of 345 knots,⁶¹ and can remain airborne for over forty hours.⁶² Its payload includes electro-optical sensors, infrared sensors, and synthetic aperture radars with movement target indicators.⁶³ Global Hawk has three modes of navigation: Preprogrammed; Autonomous, and Direct control (**see Appendix 1, Glossary of Terms**).⁶⁴ Global Hawk's published ceiling is 65,000 feet.⁶⁵

The last two UAVs in the representative sample are United States Army systems, the Hunter and the Shadow 200. The Hunter UAV program was started in 1988.⁶⁶ The Hunter's missions include day/night reconnaissance, surveillance, target acquisition, and battle damage assessment.⁶⁷ The Hunter has a range of 200 kilometers,⁶⁸ a maximum speed of 106 knots,⁶⁹ and can remain aloft for 12 hours.⁷⁰ The Hunter's payload is electro-optical and infrared cameras.⁷¹ The Hunter is remotely piloted by two ground station operators who also control the unmanned aerial vehicle's payload functions.⁷² The Hunter UAV entered service in 1996,⁷³ but the Army's newest UAV, the Shadow 200, may enter service as early as 2003.⁷⁴

The Shadow 200 is a small, lightweight, tactical unmanned aerial vehicle that is ideal for artillery targeting,⁷⁵ day/night reconnaissance, surveillance, and battle damage assessment.⁷⁶ The Shadow 200 has a range of 200 kilometers,⁷⁷ a maximum speed of 150 knots,⁷⁸ and can remain aloft for 6-8 hours.⁷⁹ The Shadow 200's payload includes electro-optical and infrared cameras and communications equipment for command and control and imagery

dissemination.⁸⁰ The Shadow 200 navigates via preprogrammed waypoints, autonomous navigation, and direct control from a ground control station.⁸¹

Table 5 is a summary of the key unmanned aerial vehicle capabilities already discussed:

KEY UNMANNED AERIAL VEHICLE CAPABILITIES						
<u>UAV SYSTEM</u>	<u>RANGE</u>	<u>MAX SPEED</u>	<u>ENDURANCE</u>	<u>PAYLOAD</u>	<u>NAVIGATION</u>	<u>MISSION</u>
DRAGON WARRIOR	100 NMs	135 KNOTS	2.5 HOURS	EO/IR	PREPROGRAMMING/ AUTONOMOUS	RECONNAISSANCE
DRAGON EYE	10 KMs	35 KNOTS	1 HOUR	EO/IR	PREPROGRAMMING/ AUTONOMOUS	RECONNAISSANCE
FIRE SCOUT	110 NMs	125 KNOTS	6 HOURS	EO/IR/LRFD/ SAR/MTI	AUTONOMOUS	RECONNAISSANCE/ TARGET AQC
PREDATOR	500 NMs	130 KNOTS	>20 HOURS	EO/IR/SAR	REMOTE PILOT CONTROL	RECONNAISSANCE/ SURVEILLANCE/ TARGET AQC
GLOBAL HAWK	3,000 NMs	345 KNOTS	>40 HOURS	EO/IR/SAR/ MTI	PREPROGRAMMING/ AUTONOMOUS/ REMOTE PILOT CONTROL	RECONNAISSANCE
HUNTER	200 KMs	106 KNOTS	12 HOURS	EO/IR	REMOTE PILOT CONTROL	RECONNAISSANCE/ SURVEILLANCE/ TARGET AQC
SHADOW 200	200 KMs	150 KNOTS	6-8 HOURS	EO/IR/C2	PREPROGRAMMING/ AUTONOMOUS/ REMOTE PILOT CONTROL	RECONNAISSANCE/ SURVEILLANCE/ TARGET AQC

TABLE 5

After examining the data in Table 5, many of the characteristics of current unmanned aerial vehicles compare favorably to the OH-58D Helicopter. For instance, range, maximum speed, and payload capabilities are as good or better than the OH-58D's range of 250 nautical mile range, maximum speed of 112 knots, and electro-optical, infrared, and laser rangefinder/designator sensor payloads.⁸² Nearly all the unmanned aerial vehicles listed above have better endurance capabilities than the OH-58D's two hours of flight time.⁸³ Only the Dragon Eye, which is focused on supporting small unit, frontline requirements, is significantly

slower, has less range, or has a shorter dwell time than the OH-58D helicopter. In summary, six of seven representative UAVs have technological capabilities equal to or better than the OH-58D. What about future UAV capabilities?

In the near-term future (**see Appendix 1, Glossary of Terms**), unmanned aerial vehicle sensor payloads, onboard weapon systems, flight characteristics, and computer programming technology are expected to rapidly progress. UAV sensor payload improvements are already on the horizon. Improvements in synthetic aperture radar (SAR) like RotoSar (**see Appendix 1, Glossary of Terms**), which employs additional antenna elements mounted within its helicopter rotor blades, and Jigsaw miniature ladar (**see Appendix 1, Glossary of Terms**), which builds three dimensional pictures of difficult targets hidden by trees and urban alleyways,⁸⁴ will increase reconnaissance effectiveness. The next generation of sensors will use electromagnetic waves to detect buried land mines,⁸⁵ sample the air to detect the presence of chemical, biological, and radiological agents,⁸⁶ and use geo-referencing systems that will simultaneously add geographic context and correct for poor video quality.⁸⁷ Finally, the Near-nadir MMW (millimeter-wave) Exploitation System (NEMESYS) (**see Appendix 1, Glossary of Terms**) receives synthetic aperture radar information and correlates three dimensional computer models to create a simple form of automatic target recognition.⁸⁸ Though these are only a few of the near-term sensor improvements under development, a multimodal⁸⁹ combination of sensor payloads operating together and simultaneously will significantly improve UAV effectiveness.

UAV weapon systems are also rapidly improving. Beyond the Predator, which has successfully launched over fifty hellfire missiles in combat situations, the United States Army is test firing Brilliant Anti-Armor (BAT) munitions from UAVs. A Hunter UAV scored four hits in four attempts against an array of moving armored targets at White Sands Missile Range, New Mexico, on 9 through 11 October 2002 using BAT munitions.⁹⁰ Soon, UAVs could feature even more advanced weapons by employing directed energy and particle beam technologies.

High-powered microwave is a form of directed energy that generates and distributes a signal powerful enough to damage electronic components, stall automobile ignitions, and scramble computer memories.⁹¹ Beyond microwave energy weapons, particle beams and advanced lasers are possible in the near-term future. These weapons are not science fiction. At White Sands Missile Range on 5 November 2002, the U.S Army used a high-energy laser to shoot down an artillery shell in mid-flight.⁹² Arming UAVs with improved weapons technologies

and multiple engagement capabilities should increase their value as armed reconnaissance vehicles.

In addition to advanced weapons, UAV flight characteristics should improve over the next ten years. One example is the small A160 Hummingbird Warrior that is currently under development. The A160 Hummingbird will exploit a hingeless, rigid rotor concept to achieve a 2,000 nautical mile range and 24-48 hours of flight, while still maintaining the ability to hover as a helicopter.⁹³ This combination enables the Hummingbird to cover great distances and maximize the effectiveness of movement target indicator (MTI) radars (**see Appendix 1, Glossary of Terms**).⁹⁴ As the sensor and communications payloads become smaller⁹⁵, the size of UAVs should shrink, further improving their endurance, speed, and stealth qualities.

Finally, improvements in computer programming will enable UAVs to operate in teams or small groups without human interaction. As an example, after detecting a potential target, a large, long range UAV might release a shorter range, smaller UAV to conduct a more detailed, lower level reconnaissance flight or even attack the target.⁹⁶ Another concept that enables UAVs to operate independently of human control is called "SWARM". The "SWARM" concept allows a group of UAVs to fly a reconnaissance mission; when an individual system in the "SWARM" is attacked, the remaining UAVs detect the fact that one of their number is missing, correlate possible enemy ADA locations, investigate those locations, and ultimately destroy the site.⁹⁷ Imagine what a "SWARM" of UAVs could do to an enemy's air defense system.

The future looks bright for UAVs. In the next ten years, their sensor payloads should continue to improve and UAVs should feature advanced weapons, break flight records, and operate in groups, but what about their limitations?

The most significant technological obstacles to expanded employment roles for UAVs are electromagnetic spectrum and artificial intelligence limitations. Areas of the electromagnetic spectrum are broken into broad categories that are called bandwidths (**see Appendix 1, Glossary of Terms**).⁹⁸ Though bandwidth limitations are not an issue when systems are hard wired together by digital cable and fiber optics, as in cable television signals, they are major limitations for digital wireless systems. This is especially true if the digital wireless communication is a video signal.⁹⁹ As an example, one recent Congressional subcommittee investigating Radio Frequency Spectrum Encroachment claimed one Global Hawk unmanned aerial vehicle consumes five times the total bandwidth consumed by the entire U.S. military during the Gulf War.¹⁰⁰

Another factor is bandwidth competition. Since Desert Storm, commercial and international interests are competing with the US military for use of the electromagnetic

spectrum. After Desert Storm, the US Government sold large portions of the spectrum, in the form of licenses, to domestic commercial activities. These commercial spectrum users developed the cell phone and commercial satellite industries. Now their activities not only restrict available sole use military bandwidth, their activities often overlap or “bleed over” onto the spectrum designated for military use.¹⁰¹ Even more significant is the international considerations. The US Government sold commercial licenses to American businesses with restrictions regarding national security issues; however, international users, such as China and the European Union, are unlikely to regard the electromagnetic spectrum as the private property of the United States.¹⁰²

These electromagnetic spectrum limitations complicate the merger of the real-time UAV sensor data and human reasoning. When humans operate Army helicopters, they collect most information visually from observation outside the cockpit or from visual indications inside the cockpit. Whether the sensor is electro-optical or infrared, the information is presented to the pilot in the form of a visual display. Beyond the aircraft's sensor display system, the human operator has other visual stimuli. The operator can look to the left, right, above and below from his cockpit and scan inside the cockpit for other information, such as instrument and warning device indications. This immediately accessible visual information is rapidly processed in the human brain to produce a decision, plan, or course of action. This rapid merger of visual information and the human thought process, called visual reasoning, is an important element in the effectiveness of Army helicopters. For a UAV to replicate the fusion of an Army helicopter and pilot, massive and continuous streams of video information are required. As discussed earlier with the Global Hawk, this massive and continuous stream of video information is not possible given the current electromagnetic spectrum limitations. This spectrum limitation is being researched.¹⁰³ However, for now, a distinct limitation is evident. Remotely embedding human visual reasoning into UAVs on a scale necessary to replicate the employment of large helicopter units is not possible, because large, real-time video display requirements exceed the capabilities of the electromagnetic spectrum. One other possibility to consider is to make UAVs capable of operating without human guidance using artificial intelligence.

Current technology does not support the artificial intelligence option. In October 1983, the Defense Advanced Research Projects Agency (DARPA) announced a \$600 million program to harness artificial intelligence.¹⁰⁴ Despite the fiscal commitment and twenty years of research, DARPA has not delivered the artificial intelligence capabilities that it promised in 1983.¹⁰⁵ The problem, in 1983 and now, is that science does not sufficiently understand the functions of the human brain to replicate, in a machine, decision making abilities. Therefore, artificially

replicating the functions of the human brain to the degree necessary to replicate “visual reasoning” in a UAV is not yet possible.

Though science does not yet understand the human brain, programmers are attempting to replicate human reasoning using computer algorithmic methods (**see Appendix 1, Glossary of Terms**). This process is laborious and achieved limited success. Today, using computer algorithmic methods, programmers can provide reasoning and thought processes on par with a cat’s brain.¹⁰⁶ Given the limited progress in the past twenty years, it seems unlikely that a revolutionary technological advancement in computer programming will equate to human reasoning in the next ten years. Therefore, bandwidth and computer programming limitations are the primary reasons why UAVs cannot achieve the visual reasoning capabilities of manned Army helicopters.

Reviewing the process to this point, this research and analysis focused on combat aviation reconnaissance, security, and movement-to-contact missions. FM 1-114, which provides the most well developed critical task lists, identified twenty-three critical tasks supporting reconnaissance, security, and movement-to-contact operations. Current unmanned aerial vehicle capabilities, including range, maximum speed, endurance, and sensors payloads, are equal to or better than the OH-58D Helicopter. Additionally, near-term future unmanned aerial vehicles will feature improved sensor payload capabilities, advanced weapons systems, and improved flight characteristics, while teaming unmanned aerial vehicles on specific mission profiles, but due to bandwidth and programming limitations unmanned aerial vehicles will not achieve visual reasoning; an essential quality in order for them to replace manned helicopters in all tasks.

The only remaining requirement in step three of this research project is to develop the decision criteria to compare unmanned aerial vehicle capabilities and limitations against Army helicopter critical tasks supporting reconnaissance, security, and movement-to-contact missions. Since unmanned aerial vehicle sensor capabilities, today and in the near-term future (**see Appendix 1, Glossary of Terms**), are equal to or better than Army helicopter sensor capabilities, UAVs can accomplish any critical task that only requires this capacity. And, since unmanned aerial vehicles possess autonomous navigation and pre-launch waypoint programming capabilities, any critical task that can be accomplished with pre-launch data is also within the UAV’s capacity. However, since unmanned aerial vehicle technology will not support visual reasoning, critical tasks that require visual reasoning are beyond the UAV’s capability.

Table 6 is a summary of the decision criteria explained above:

DECISION CRITERIA

1. UAVs can accomplish critical tasks requiring sensor capabilities.
2. UAVs can accomplish critical tasks executable with pre-launch flight data.
3. UAVs cannot accomplish critical tasks requiring visual reasoning.

TABLE 6

COMPARING UAV CAPABILITIES AND LIMITATIONS AGAINST AVIATION CRITICAL TASKS - STEP 4

Using preprogrammed waypoints and multimodal sensors, current and near-term future UAVs can accomplish eleven of the twenty-three critical tasks supporting reconnaissance, security, and movement-to-contact missions. The eleven critical tasks are listed below (numbering reflects Table 4, page 7):

1. Report reconnaissance information.
2. Find and report all enemy in zone.
3. Reconnoiter all terrain within the area, within the zone, and all terrain that can dominate the area.
4. Determine significant adverse weather.
7. Locate fords and crossing sites near all bridges in the zone or area.
8. Locate all mines, obstacles, and barriers in the zone or area within capabilities.
12. Maintain continuous surveillance of all battalion-sized avenues of approach.
14. Perform reconnaissance along the main body's axis of advance.
17. Maintain contact with the lead combat element of the friendly force.
18. Reconnoiter the zone between the main body and the guard force battle positions.
20. Reconnoiter forward or to the flanks of ground forces.

Unmanned aerial vehicles, using preprogrammed waypoints and multimodal sensors, can conduct reconnaissance, security, and movement-to-contact tasks designed to investigate terrain, search predetermined areas to find enemy forces, provide early warning to a moving force, or observe particular locations. Ten of these reconnaissance, security, and movement-to-contact tasks require standard sensor payloads, i.e. electro-optical, infrared, and synthetic

aperture radar. Only one of these eleven tasks, *determining significant adverse weather*, might require a unique sensor payload to determine wind, temperature, or other environmental conditions. Reporting information is required in all eleven of these tasks. Ideally, sending this information by video signals is the preferred method in most cases, but not the only method. The operator could wait for the return of the unmanned aerial vehicle, or the unmanned aerial vehicle could send a brief audio signal back to the operator immediately and fill in the details later. Whatever the method of returning the data, a UAV equipped with a multimodal sensor array and preprogrammed waypoint navigation could successfully accomplish these critical tasks.

Of the twelve remaining critical tasks supporting reconnaissance, security, and movement-to-contact missions, eleven require visual reasoning; the process of gathering data through optical senses, whether from instruments, aircraft sensor displays, and/or human observation, and developing a course of action or recommendation using individual analytical skills. These eleven critical tasks are (numbering reflects Table 4, page 7):

5. Inspect and classify all bridges, overpasses, underpasses, and culverts within the area.
9. Locate sites for constructing hasty obstacles to impede enemy movement.
10. Reconnoiter all defiles along route for possible ambush sites and locate a bypass.
11. Find suitable covered and concealed air avenues of approach.
13. Destroy or repel all enemy reconnaissance and security forces.
15. Locate the lead elements of the enemy order of battle.
16. Maintain contact with the enemy order of battle, report their activities, and harass the enemy while displacing.
19. Defeat, repel, or fix enemy ground forces before they engage the main body with direct fire.
21. Harass and impede enemy elements.
22. Direct ground elements to the vicinity of enemy forces and support friendly forces with direct fires.
23. Maintain surveillance of enemy forces.

Ten of these eleven visual reasoning critical tasks involve a dynamic enemy force. In each critical task, the enemy force has multiple options, the pilot of the Army helicopter has multiple options, and both are influenced by terrain, weather and friendly forces. The helicopter

pilot must rapidly analyze all available information, determine the most probable enemy course of action, and select the appropriate course of action to defeat that enemy plan. Once he chooses his course of action, the helicopter pilot must monitor the enemy force, friendly forces, terrain, and weather for any changes that might necessitate altering his plan. Successfully operating in this dynamic, uncertain situation requires mental agility and flexibility; UAVs, lacking visual reasoning, do not possess this mental agility and flexibility. Visual reasoning is an absolute minimum requirement for the successful execution of these ten critical tasks.

The one other visual reasoning critical task, *inspect and classify all bridges, overpasses, underpasses, and culverts within the area*, though not influenced by dynamic enemy actions, still requires visual reasoning. To accomplish this critical task, the helicopter pilot must determine if the structure is capable of supporting friendly forces needs. If so, are there any limitations on its usage? Next, the helicopter pilot must determine if the structure is damaged. If the structure is damaged, how badly is it damaged? Can it still be used? Can it be repaired? If it can be repaired, what assets are necessary to make the repairs? If the structure is beyond repair, can parts or all of it be bypassed? While the helicopter pilot is inspecting the structure, sometimes on foot, his supported friendly force might be moving toward that structure intent on using it. Large convoys are vulnerable targets, especially if they are stationary and close together. If they arrive at the structure, only to find it unusable, that convoy will be vulnerable. Multimodal UAV sensor payloads might enhance execution of this critical task, but visual reasoning is required to rapidly evaluate the situation and develop a plan of action.

The remaining critical task, *locating bypasses around built-up areas, obstacles, and contaminated areas*, is best accomplished by a combination of manned and unmanned systems coupling multimodal sensors with visual reasoning. This critical task has two elements, detecting what must be bypassed and determining how to bypass it. Both manned and unmanned systems can detect and determine bypasses around built-up areas. However, it is more difficult to detect well camouflaged obstacles or the limits of chemical, biological, and radiological contamination, with visual detection alone. Multimodal, non-optical sensors can detect areas of contamination or locate mines, obstacles, and/or barriers that are too well camouflaged for optical sensors. This type of detector system or systems will scan for manmade concentrations of metal, small changes in earth's surface heat due to recent upheaval, or use wind sensors that can detect trace NBC elements in the air. However, the capability to detect manmade obstacles, obstructions, or unnatural concentrations of lethal or incapacitating substances is of little value without the ability to analyze the threat caused by these impediments and determine how to negate them. Analyzing the potential threats and

circumventing them can only be accomplished by visual reasoning. Therefore, both manned and unmanned systems working together can most successfully accomplish this critical task.

Table 7, below, summarizes which critical tasks supporting reconnaissance, security, and movement-to-contact missions UAVs and helicopters can successfully execute.

CRITICAL TASKS	UAV	HELICOPTERS	BOTH
	SYSTEMS		
1. Report Reconnaissance information.	YES	YES	YES
2. Find and report all enemy in zone.	YES	YES	YES
3. Reconnoiter all terrain within the area, within the zone along the route, and all terrain that can dominate the area.	YES	YES	YES
4. Determine significant adverse weather.	YES	YES	YES
5. Inspect and classify all bridges, overpasses, underpasses, and culverts within the area.	NO	YES	YES
6. Locate a bypass around built-up areas, obstacles, and contaminated areas.	NO	NO	YES
7. Locate fords and crossing sites near all bridges within zone or area.	YES	YES	YES
8. Locate all mines, obstacles, and barriers in the zone within its capabilities.	YES	NO	YES
9. Locate sites for constructing hasty obstacles to impede enemy movement.	NO	YES	YES
10. Reconnoiter all defiles along route for possible ambush sites and locate a bypass.	NO	YES	YES
11. Find suitable covered and concealed air avenues of approach.	NO	YES	YES
12. Maintain continuous surveillance of all battalion-sized avenues of approach.	YES	YES	YES
13. Destroy or repel all enemy reconnaissance and security forces.	NO	YES	YES
14. Perform reconnaissance along the main body's axis of advance.	YES	YES	YES
15. Locate the lead elements of the enemy order of battle.	NO	YES	YES
16. Maintain contact with the enemy order of battle report their activities, and harass the enemy while displacing.	NO	YES	YES
17. Maintain contact with the lead combat element of the friendly force.	YES	YES	YES
18. Reconnoiter the zone between the main body and the guard force battle positions.	YES	YES	YES
19. Defeat, repel, or fix enemy ground forces before they engage the main body with direct fire.	NO	YES	YES
20. Reconnoiter forward or to the flanks of ground forces.	YES	YES	YES
21. Harass and impede enemy elements.	NO	YES	YES
22. Direct ground elements to the vicinity of enemy units and support friendly ground forces with direct fires	NO	YES	YES
23. Maintain surveillance of enemy forces.	NO	YES	YES

TABLE 7

Though Table 7 is useful in the examination of each individual critical task, it does not link them to their doctrinal missions. By examining UAV capabilities against the critical tasks associated with each reconnaissance, security, and movement-to-contact mission, the analysis will shed some light on which missions UAVs can successfully accomplish without human

assistance. Given the potential lower cost and risk of performing missions with UAVs versus manned Army helicopters, any mission UAVs can successfully accomplish has the benefit of reducing risks to soldiers and reducing the overall cost of conducting operations.

Unmanned aerial vehicles cannot execute all the critical tasks supporting aviation reconnaissance missions. However, unmanned aerial vehicles can execute eight of the nine critical tasks required for area reconnaissance operations. The exception is *bridge, culvert, and overpass and underpass inspections and classifications*. Considering that an area reconnaissance operation is initiated to gain specific information on a particular site, unmanned aerial vehicles can successfully execute area reconnaissance missions unless specific information is required on bridges, culverts, overpasses and underpasses in that area. Similarly, unmanned aerial vehicles can execute eight of the ten critical tasks associated with zone reconnaissance operations; the exceptions are, again, *inspection and classification of bridges, culvert, overpasses and underpasses*, and *finding suitable covered and concealed air avenues of approach*. The limitation concerning manmade structures is more significant in this mission since zone reconnaissance operations cover greater expanses of terrain, increasing the likelihood of finding structures to inspect and classify. More perplexing is the requirement to find suitable covered and concealed air avenues of approach. As an unmanned aerial vehicle self-protection mechanism, accomplishing this critical task is not particularly significant, especially if the unmanned aerial vehicle is a relatively low cost system. However, if accomplishing the air avenues of approach critical task is necessary to satisfy a future use by manned systems, then this is a significant limitation. Given these limitations, unmanned aerial vehicles are less satisfactory for zone reconnaissance operations. Lastly, unmanned aerial vehicles can satisfactorily accomplish five of the seven critical tasks associated with route reconnaissance operations. The limitation here relates to visual reasoning, the ability to recognize *opportunities to canalize enemy forces or opportunities for the enemy to do the same to friendly forces*. These weaknesses are significant since the inability to perform these critical tasks could have catastrophic impacts on friendly forces. After cross referencing the critical tasks from Table 7, above, with the consolidated reconnaissance critical tasks listed in Table 1 on page 4, unmanned aerial vehicles can successfully execute seven of eleven critical tasks, or 67% of the critical tasks associated with reconnaissance operations. This revelation is especially important to understand since unmanned aerial vehicles are widely touted as ideally suited to replace manned helicopters for conducting reconnaissance operations.

Unmanned aerial vehicles cannot execute all the critical tasks supporting aviation security missions. Unmanned aerial vehicles can only perform one in four (25%) of the critical

tasks associated with screen operations. The unmanned aerial vehicles' inability to react to enemy contact is the root cause of its unsuitability for screen operations. This is not surprising since identifying enemy formations, engaging them as they move, and maintaining contact while both forces are moving requires well developed visual reasoning skills. Unmanned aerial vehicles can perform four of six (67%) critical tasks supporting aviation role's in guard operations. As discussed with screen operations, the dynamic situation is the limiting factor for UAVs in guard operations. Movement-to-contact missions are no different.

UAVs can only execute one of four (25%) critical tasks associated with movement-to-contact missions. Again, the inability to deal with dynamic enemy situations demonstrates clearly that UAVs are unsuitable for this operation. As before, making a cross reference between the critical tasks from Table 7 on page 19, and the consolidated security critical tasks listed in Table 2 on page 6, UAVs can only accomplish four of eight critical tasks, or 50% of the critical tasks associated with security missions. When the four movement-to-contact critical tasks are added to the eight security critical tasks creating a more comprehensive critical tasks list, the percentage, a mere 5 of 12 or a 41% success rate, shows clearly that unmanned aerial vehicle's are unsuitable for these missions.

The primary question in this strategic research paper was whether or not unmanned aerial vehicles could fulfill the role of Comanche helicopters in the next ten years. Though UAV technical capabilities are equal to or better than current helicopters, unmanned aerial vehicles can only accomplish 67% of the tasks associated with reconnaissance missions, 50% of the tasks associated with security missions, and 25% of the tasks associated with movement-to-contact missions. These percentages demonstrate that the employment of unmanned aerial vehicles in lieu of Comanche helicopters leaves the force at risk. Therefore, the answer to the primary question is no, unmanned aerial vehicles, now or in the next ten years, cannot fulfill the role of Comanche Helicopters.

Since the analysis clearly shows that UAVs cannot replace manned helicopters in reconnaissance, security, and movement-to-contact missions, why are UAVs frequently touted as replacements for manned helicopters? One reason is ease of comparing UAVs and helicopters in a purely statistical fashion. For instance, the Hunter has six times more flight time endurance than an OH-58D and would lead some people to equate endurance with all-round mission capability and incorrectly conclude that the Hunter six times better than an OH-58D. A second example of erroneous analysis is comparing armed UAVs and helicopters. The armed UAV has been successful in small scale operations; operations with finite friendly forces and limited numbers of potential targets. In this small scale environment, UAV video signals are

sent back to operators for the decision to engage or not. With a limited number of UAVs executing missions simultaneously, existing bandwidth can support the requirements. However, if the armed UAVs tried to replicate a helicopter unit, such as a divisional air cavalry troop (six to eight systems) on a movement-to-contact mission, existing bandwidth could not support the requirements. Therefore, without dramatic improvement in bandwidth or artificial intelligence technologies, arming UAVs is strictly limited to small scale operations involving few targets. A third reason why UAVs are frequently mentioned as replacements for manned systems is the risk to human life. When a manned helicopter is operated in a hostile environment, the potential to be shot down puts American lives at risk. When a UAV is lost, no lives were ever at risk; no Americans can be taken prisoner. The risk problem is solved. A spokesperson tells the media that a UAV was lost trying to perform a difficult mission. The matter is closed, no lingering issues, no horrific images of Americans or their remains paraded in front of the international media. Neat, clean, easy. But if the UAV is incapable of accomplishing the mission, launching it is meaningless. A fourth reason is the UAV's proven success in strategic and operational reconnaissance operations versus the reconnaissance missions performed at the tactical level. This research demonstrates that success in the strategic and operational levels of war does not equate to success at the tactical level because UAVs can only accomplish 47% of the critical tasks. Accomplishing the reconnaissance, security, movement-to-contact critical tasks equates to success on the tactical battlefield. Therefore, these individuals who tout UAVs as replacements for manned systems may have pure motives, but they are wrong to suggest UAVs can replace manned helicopters. And, their failure to understand why UAVs are not the panacea to reduce equipment cost and risk to human life is probably not their fault; the fault lies with professional soldiers who likewise do not understand the critical differences between these systems and their suitability to perform certain combat tasks.

The Army's greatest weapon is the mind of a well trained soldier. Training soldiers takes time, but the benefits are limitless. Using an example from this research project, training a helicopter pilot to understand enemy employment considerations, his own employment considerations, the effects of terrain and weather on both, and rapidly determining the right course of action takes time. The time to train, the time to learn, the time to develop the skills necessary to recognize opportunities demonstrate the U.S. Army's investment in the minds of its soldiers. The pilot's mental agility and flexibility are coupled with the helicopter's speed and maneuverability; that is the real weapon. Until professional soldiers articulate to our superiors why UAVs cannot fulfill the role of well-trained helicopter crews, the perception that UAVs can

replace manned helicopters will continue to persist and may negatively affect future decisions concerning aviation force structure and budgets.

A BRIEF OVERVIEW OF IMPROVING CAPABILITIES – STEP 5

Since this strategic research project has identified a shortfall between critical tasks supporting aviation missions and unmanned aerial vehicle capabilities, a secondary purpose of this research is to briefly discuss how the Army might close the gap between mission requirements and unmanned aerial vehicle capabilities. The best near-term solution is to combine manned with unmanned systems in tactical operations. The technology is already available to launch small unmanned aerial vehicles from larger unmanned aerial vehicles. This same technology would enhance the reconnaissance and survivability capabilities of manned systems. Another possibility is to synchronize the flight of manned vehicles with unmanned aerial vehicles. Imagine the increased potential of a manned system if it had an unmanned aerial vehicle on its left and right flanks, doubling or even tripling its coverage area. Yet another possibility is a dual role unmanned aerial vehicle. This dual role unmanned aerial vehicle could launch from a helicopter, serve as short range sensor platform, and, when necessary, convert into a precision guided weapon.

Unmanned aerial vehicles cannot, now or in the near-term future (**see Appendix 1, Glossary of Terms**), replaced manned Army helicopters in the performance of any reconnaissance, security, and movement-to-contact missions. However, combining UAVs with manned helicopters should provide synergistic effects and greatly improve the reconnaissance, security, and movement-to-contact capabilities of the U.S. Army.

WORD COUNT = 7,097

APPENDIX 1, GLOSSARY OF TERMS

Algorithmic methods - A sequence of steps designed for programming a computer to solve a specific problem.

Autonomous navigation - The ability of a mechanical system, in this case a UAV, to detect its current location, analyze its current location relative to its intended location, and make independent flight adjustments to return itself to its intended location and flight path without assistance, analysis, or input from a ground control station. In effect, the machine determines its current location, evaluates whether it is on course or not, and if not on the correct course, makes flight control inputs to return itself to the correct course.

Bandwidth – The width of a band of electromagnetic frequencies. In the simplest terms, consider bandwidth a road and information a car. The wider the road the more cars it can support at any one time.

Direct control – Remotely piloted by a trained operator on a ground control station.

Jigsaw miniature ladar - A synthetic aperture type radar which can build up a three-dimensional picture of difficult targets such as those hidden by trees or within urban alleyways.

Movement target indicator - An electronic device which will permit detects moving targets by detecting their Doppler Shift as they move.

Near-nadir MMW (millimeter-wave) Exploitation System (NEMESYS) – A synthetic aperture type radar which can build up a three-dimensional picture of difficult targets such as those hidden by trees or within urban alleyways, but uses a different electromagnetic spectrum frequency band than the Jigsaw miniature ladar. .

Near-term future - Within the next ten years, e.g. 2013.

Preprogramming waypoints - Manually selecting flight check points for an unmanned aerial vehicle to fly after launch and loading those check points prior to launch.

RotoSar – A synthetic aperture type radar which has its antenna mounted within its rotor blades.

Synthetic aperture radar – A radar system that produces a two dimensional image of an object by projecting transmission pulse and reading the echo of that pulse in azimuth and range.

ENDNOTES

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⁸⁰ "RQ-7 Shadow 200 Tactical Unmanned Aerial Vehicle (TUAV) System," 2001; available from <<http://www.globalsecurity.org/military/library/bdget/fy2001/dot-e/ary/01shadow.htm>>; Internet; accessed 20 November 2002.

⁸¹ "Shadow 200," n.d. Available from <<http://www.uavforum.com/vehicles/developmental/shadow200.htm>>; Internet; accessed 29 October 2002.

⁸² Christopher Bolkcom, "Army Aviation: The RAH-66 Comanche Helicopter Issue," CRS Report for Congress 9 January 2002; database on-line; available from STINET; Internet; accessed 15 October 2002.

⁸³ This fact is drawn from the author's experience as an OH-58D Army Aviator. The author completed initial OH-58D qualification in 1992 and served as an OH-58D observer/controller in the National Training Center, Fort Irwin, California, an OH-58D equipped attack helicopter battalion executive and operations officer in Fort Drum, New York, and an OH-58D equipped attack helicopter battalion commander in Fort Hood, Texas and Wheeler Army Airfield, Hawaii. Ambient temperature, altitude above sea level, and aircraft weight significantly influence OH-58D endurance, but two hours of flight time between refuel stops is generally a good planning figure.

⁸⁴ Mark Hewish, "Unmanned, unblinking, undeterred," Jane's Defense Magazine Online 20 August 2002; database on-line; available from Janes.com; accessed 1 November 2002.

⁸⁵ "Robotic Aircraft on Reconnaissance," Futurist vol. 36, issue 5, September 2002; database on-line; available from STINET; accessed 15 October 2002.

⁸⁶ Robert Wall, "Predator UAV Tested With New Payloads," Aviation Week & Space Technology vol. 157, issue 10, 2 September 2002; database on-line; available from STINET; accessed 15 October 2002.

⁸⁷ Mark Hewish, "Unmanned, unblinking, undeterred," Jane's Defense Magazine Online 20 August 2002; database on-line; available from Janes.com; accessed 1 November 2002.

⁸⁸ Ibid.

⁸⁹ "Robotic Aircraft on Reconnaissance," Futurist vol. 36, issue 5, September 2002; database on-line; available from STINET; accessed 15 October 2002.

⁹⁰ "BAT Submunition Released from Hunter UAV Scores Direct Hits in U.S. Army-Northrop Grumman Tests," Northrop Grumman Company Announcement 21 October 2002 (501 words); database on-line; available from Lexis-Nexis; accessed 23 October 2002 and "Army, TRW complete drop of armed BATS from UAV," Aerospace Daily vol. 204, no. 12, p. 5 (181 words); database on-line; available from Lexis-Nexis, accessed 23 October 2002.

⁹¹ Ibid.

⁹² Charles Aldinger, "Army Shoots Down Artillery Shell with Laser," Reuters 5 November 2002; database on-line; available from yahoo.com; accessed 6 November 2002.

⁹³ "Hummingbird Warrior," 17 October 2002; available from <http://www.darpa.mil/tto/programs/hum_war.htm>; Internet; accessed 3 November 2002.

⁹⁴ Mark Hewish, "Unmanned, unblinking, undeterred," Jane's Defense Magazine Online 20 August 2002; database on-line; available from Janes.com; accessed 1 November 2002.

⁹⁵ Two factors contribute to the reduction in payload size, miniaturization and Moore's Law, which states that computer processing power will double every eighteen months.

⁹⁶ Robert Wall, "Predator UAV Tested with New Payloads," Aviation Week & Space Technology 2 September 2002, vol. 157, issue 10; database on-line; available from STINET; accessed 15 October 2002.

⁹⁷ Mary Zoccola, "Homegrown, Affordable Concept to be Produced for Navy Use," Wavelengths March 2001; available from <http://www.dt.navy.mil/pao/excerpts%20pages/2001/UAV3_01.htm>; Internet; accessed 29 October 2002.

⁹⁸ "Bandwidth," What's?com 5 October 2000; available from <http://whatis.techtarget.com/definition/0,289893,sid9_gci211634,00.htm>; Internet; accessed 3 November 2002.

⁹⁹ Ibid. As an example, a voice signal has a bandwidth of approximately three kilohertz, but an analog television broadcast video signal has a bandwidth of six megahertz, 2,000 times as wide as the voice signal.

¹⁰⁰ Jason Chung, "Media Advisory: Congressman Christopher Shays to Hold April 23 Hearing on Radio Frequency Spectrum Encroachment," 18 April 2002; available from <http://www.house.gov/reform/ns/statement_witness/media_advisory_april23.htm>; Internet; accessed 25 November 2002.

¹⁰¹ Theresa Foley, "The Battle for Bandwidth," *Air Force Magazine Online* October 1999, vol. 82, no. 10; available from <<http://www.afa.org/magazine/Oct1999/1099bandwidth.htm>>; Internet; accessed 25 November 2002.

¹⁰² Jason Chung, "Media Advisory: Congressman Christopher Shays to Hold April 23 Hearing on Radio Frequency Spectrum Encroachment," 18 April 2002; available from <http://www.house.gov/reform/ns/statement_witness/media_advisory_april23.htm>; Internet; accessed 25 November 2002.

¹⁰³ "US Air Force targets UAV bandwidth problem," *Defense News Briefs Online* 1 August 2002; available from <http://www.janes.com/defense/air_force/news_briefs/jdw020801_04.shtml>; Internet; accessed 18 November 2002.

¹⁰⁴ Tom Athanasiou, "Mind Games," n.d.; available from <<http://www.procesedworld.com/Issues/issues13/i13mindgames.htm>>; Internet; accessed 20 January 2003.

¹⁰⁵ Ibid.

¹⁰⁶ William B. Scott, "UAVS/UCAVS Finally Join Air Combat Teams," *Aviation Week & Space Technology* 8 July 2002, vol. 157, Issue 2; database on-line; available from EBSCO; accessed 23 October 2002.

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